Auditory central nervous system plasticity: application to cochlear implantation

SYDNEY '97
XVI World Congress of Otorhinolaryngology Head and Neck Surgery

Sydney, Australia
2-7 March 1997

G.M. CLARK

Department of Otolaryngology
The University of Melbourne (AUS)
The Bionic Ear Institute, Melbourne (AUS)

PLASTICITY - EXPERIMENTAL ANIMAL

There are two types of plasticity in the central auditory nervous system. The first type occurs during the development of neural connections within a critical period after birth. The second type of plasticity results from a change in the central representation of neurons in the mature animal after neural connectivity has been established.

Evidence of a critical period for plasticity in the central auditory system has been demonstrated in the ferret where a marked loss of neurons in the cochlear nucleus occurs after ablation of the cochlea five days after birth (Moore, 1990). However, ablation of the cochlea 24 days post-partem (i.e. a week before the onset of hearing) has little effect.

An example of developmental plasticity is the increase in the number of projections in the gerbil from the cochlear nucleus to the ipsilateral inferior colliculus if the cochlea on the opposite side is destroyed in the neonate (Nordern et al., 1983). A similar phenomenon was demonstrated in the ferret (Moore and Kowalchuk, 1988). It was also observed that the critical period for this neural modelling was longer than for neuronal loss referred to above, and extended to postnatal days 40 to 90.

In post-developmental plasticity in the mature animal if an area of the cochlea is destroyed in the guinea pig, the corresponding area of the brain, in particular the cortex, has increased representation from the neighbouring frequency areas which are still functional (Robertson and Irvine, 1989). This post-developmental plasticity probably occurs because there is loss of inhibition which normally suppresses the input from neighbouring frequency areas. It has also been shown in the cat that there is reorganisation of the topographical map in the primary auditory cortex contralateral to the lesioned side, but the cortical field was normal for ipsilateral excitation from the unlesioned cochlea (Rajan et al., 1993). In addition, behavioural training has been found to modify the tonotopic organisation of the primary auditory cortex in the primate. Recanzone et al. (1993) report an increase in cortical representation for frequencies where there was improved discrimination.

COCHLEAR IMPLANTS - DEVELOPMENTAL PLASTICITY

Developmental plasticity is important in the case of cochlear implantation in children, and post-developmental plasticity has implications for implantation in older children and adults.

We have been studying plasticity in children with cochlear implants by firstly determining the critical period for speech perception during electrical stimulation with a speech processor. Results as shown in Fig. 1 indicate that speech perception is significantly better the younger the child. The data also indicates a critical period for speech perception up to approximately 4-6 years of age, however, performance starts to plateau at about 12-14 years of age.

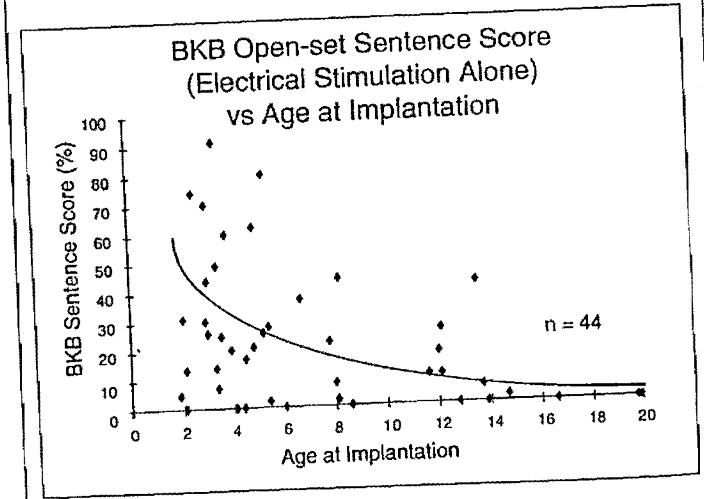

Figure 1
BKB open-set sentence scores for electrical stimulation alone versus age at implantation.

Further support for developmental plasticity is the fact that children with some residual hearing obtain better speech perception results than those without residual hearing. This is shown in Fig. 2. The data suggests that some prior exposure to sound during the critical period leads to a more normal neural connectivity, which can be better utilized with electrical stimulation from a cochlear implant.

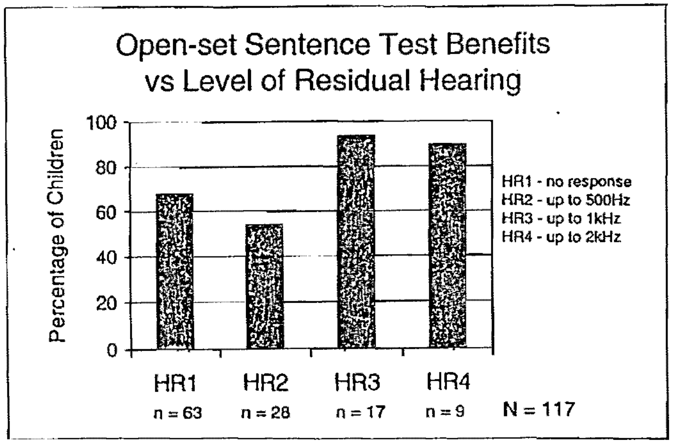

Figure 2
Percentage of children gaining open-set sentence scores for electrical stimulation alone in the categories: HRI - no residual hearing; HR2 - residual hearing up to 500Hz; HR3 - residual hearing up to 1kHz; HR4 - residual hearing up to 2kHz.

We are also studying developmental plasticity in cochlear implant children by comparing their abilities to discriminate electrode place of stimulation with age. The results show a correlation between the ability to discriminate electrodes and age. In other words, the younger the child the better they are able to distinguish between sites of electrode stimulation. We have also compared the ability of children to discriminate between stimulation of different electrode sites and their closed-set word test results. The findings show a positive correlation between stimulation at different electrode sites and closed-set word recognition. This suggests that electrode discrimination is one skill associated with the developmental of speech perception. However, if we compare the ability of children to rank pitch tonotopically rather than just discriminate electrode place, with a test of speech perception we see that not all children who rank pitch have good speech perception. This suggests that developmental plasticity affects pitch perception and speech recognition differently. For example, the critical period for pitch perception may last longer than that for speech perception.

We have also carried out a study to see if we could use plasticity to improve speech perception in children who had reasonable electrode discrimination, but this did not match their ability to perceive vowels with a comparable overlap in formant frequencies. The training was mainly analytic but some synthetic training occurred in which the discrimination of vowels were incorporated into the language. It was found that two of the four children improved in their abilities to distinguish vowel pairs. In one child gains of minimal vowel pair recognition carried over to improved speech recognition. These results suggest that training in the perceptual task of discriminating vowels during the critical period may carry over to speech perception.

COCHLEAR IMPLANTS - POST-DEVELOPMENTAL PLASTICITY

We have examined the effects of post-developmental plasticity in older children when

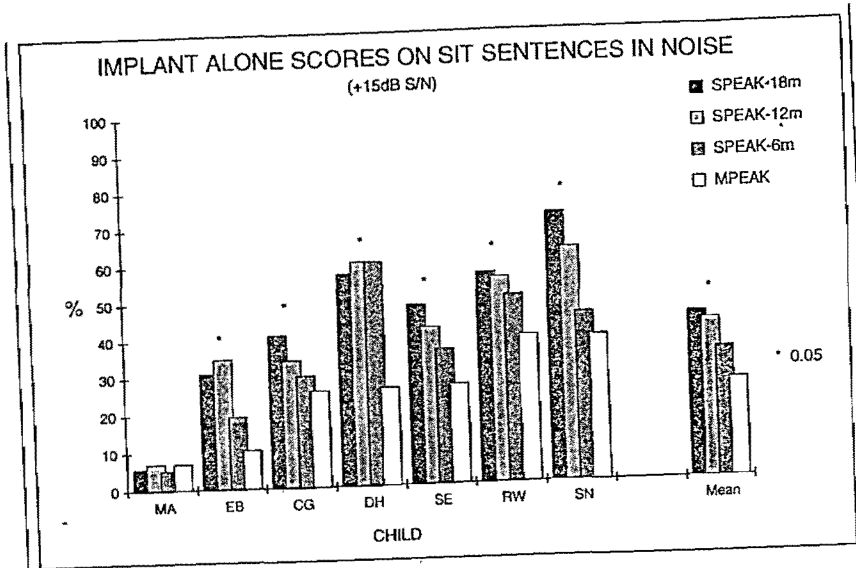

Figure 3
SIT open-set sentence scores for electrical stimulation alone in noise (15dB S/N) for MULTIPEAK and SPEAK (6 months, 12 months and 18 months post-operatively).

we have compared the results of changing children from the Multipeak to the Speak speech processing strategies. The Multipeak strategy selects up to five spectral peaks and stimulates at a rate proportional to the voicing frequency. On the other hand, the Speak strategy selects six or more spectral maxima and stimulates at a constant rate with amplitude variations conveying voicing information. Results in Fig. 3 reveal a significant improvement in speech perception scores for 6 out of 7 children. These results suggest that although children have learned to associate certain spectral and temporal patterns for cortical stimulation, with words, they can readjust to the new strategy and this may be as a result of post-developmental plasticity. Further evidence for post-developmental plasticity has been seen in a pilot study in a patient where the vowel spaces were mapped at different intervals after implantation. With the normal two formant vowel space there was a limited range or grouping of frequencies required for the perception of each vowel. With electrical stimulation, at first there was a greater number of electrodes contributing to the perception of each vowel. Furthermore, there was a greater variability in the results initially. After use and training the vowel spaces came to more closely resemble those for normal hearing.

In conclusion, it is important to emphasize that with improved knowledge of developmental and post-developmental plasticity on the perception of simple and complex signals, the more we should understand better why patient results vary and how to improve speech processing and perception.

REFERENCES.

Moore, D.R. (1990), Auditory Brainstem of the Ferret: Early Cessation of Developmental Sensitivity of Neurons in the Cochlear Nucleus to Removal of the Cochlea. J. Comp. Neurol. 302: 810-823.

Moore, D.R. & Kowalchuk, N.E. (1988), Auditory Brainstem of the Ferret; Effects of Unilateral Cochlear Lesions on Cochlear Nucleus Volume, and Projections to the Inferior Colliculus. J. Comp. Neurol. 272: 503-515.

Nordern, K.W., Killackoy, H.P. & Kitzes, L.M. (1983), Ascending Projections to the Inferior Colliculus Following Unilateral Cochlear Ablation in the Neonatal Gerbil, Mexiones Unguiculatus. J. Comp. Neurol. 214: 144-153.

Racanzone, G.H., Scheiner, G.E. & Merzenich, M.M. (1993), Plasticity in the Frequency Representations of Primary Auditory Cortex Following Discrimination Training in Adults and Monkeys. J. Neurosci. 13: 87-103.

Rajan, R., Irvine, D.R.F., Wise, L.Z. & Heil, R. (1993), Effect of Unilateral Partial Cochlear Lesions in Adult Cats on the Representation of Lesioned and Unlesioned Cochleas in Primary Auditory Centres. J. Comp. Neurol. 338: 17-49.

Robertson, D. & Irvine, D.R.F. (1989), Plasticity of Frequency Organization in Auditory Cortex of Guinea Pigs with Partial Unilateral Deafness. J. Comp. Neurol. 282: 456-471.